DISEASES ASSOCIATED WITH *JUNIPERUS OSTEOSPERMA* AND A MODEL FOR PREDICTING THEIR OCCURRENCE WITH ENVIRONMENTAL SITE FACTORS

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ABSTRACT.—On 17 Utah juniper (*Juniperus osteosperma* [Torrey] L.) sites studied in Utah, *Gymnosporangium inconspicuum* was the most common rust fungus, followed in frequency and severity by *G. nelsoni*, *G. kernianum*, and *G. speciosum*. The incidence of *G. kernianum* was correlated with moderate temperatures and greater than average precipitation. True mistletoe, *Phoradendron juniperinum* Engelm., was present on seven sites. Incidence of foliage diseases of the mold-mildew type was low on sites with low spring and summer temperatures and high on sites with high summer and fall precipitation. Wood rot was common, and incidence seemed to be correlated with low winter temperatures and low soil nitrate but not with annual precipitation. Needle blight, shoot dieback, and needle cast symptoms were common and considered of abiotic origin. Their nonparasitic nature was indicated by lack of association with pathogenic organisms and the positive correlation of their incidence with winter injury and summer drought factors. Needle blight was also positively correlated with high soil salinity but negatively with high soil calcium regardless of salinity.

A nonparametric model was developed that accurately predicted the frequency of the mold-mildew type diseases of *J. osteosperma* based on measured environmental site factors.

The pinyon-juniper woodland is a widespread vegetation type in the southwestern United States, estimated to cover from 30 to 40 million hectares (Allred 1964). Historically, pinyon-juniper woodland vegetation has provided numerous benefits including fuel, building materials, charcoal, nuts, Christmas trees, medicines, etc. (Tueller et al. 1979, Hurst 1977, Lanner 1975, Cronquist et al. 1972, Gallegos 1977). About 80% of the total acreage is grazed, contributing significantly to the available forage for livestock and wildlife (Clary 1975), and pinyon-juniper woodlands are becoming increasingly valued for their watershed, aesthetic, and recreational values (Gifford and Busby 1975).

This ecosystem is a large component of the vegetation of Utah (62,705 km^2 or 28.6%, Kuchler 1964), and it has the potential to add substantially to the economic and aesthetic activity of the state. Despite this potential, little research has been done to explore the physiological relationships and autecology of this vegetation type.

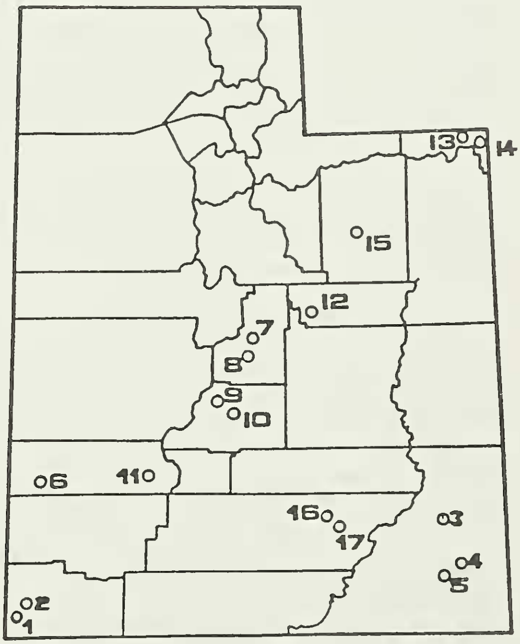

Fig. 1. Location of 17 study sites in Utah.

Many complex environmental factors contribute to the variety of interactions in a pinyon-juniper ecosystem. Consumable "supply factors" of the environment such as light, water, nutrients, oxygen, and carbon dioxide interact with "site quality" or "condition" factors such as temperature and precipitation (Harper 1977). The effects of species density,

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TABLE 1. Description of symptoms and assessment methods for diseases of *Juniper osteosperma*.

Injury	Diseases of *J. osteosperma* symptom or sign	Rating scale
Needle blight	Senescent or decadent foliage or twigs. Terminals may show yellow or red-brown coloration. May or may not show evidence of fungal fruiting bodies.	Percent of the total plant affected
Needle cast	Bare twig terminals from which foliage scale leaves have fallen (twig terminals of living branches).	Percent of the total plant affected
Tip dieback	Senescent or decadent foliage or twig terminals showing brown to grey coloration. May or may not show evidence of fungal fruiting bodies.	Percent of the total plant affected
Pathogen		
Gymnosporangium rusts:		
G. inconspicuum	Presence of follicolous or caulicolous telia having cartiform pedicels accompanied by little or no fasciation of branches.	Rated as light, moderate, or heavy: a) light: 1–3 telial infections in a 2 ft breast high circumference section of tree. b) moderate: 4–10 telial infections in equivalent area. c) heavy: more than 10 telial infections in equivalent area.
G. nelsoni	Presence of galls with irregularly compressed, wedge-shaped telia; on twigs or branches.	Actual or estimated number of galls per tree.
G. kernianum	Presence of well-defined or modified witch's brooms (branch fasciation) with foliicolous, bluntly conical telia.	Actual or estimated number of witch's brooms per tree.
G. speciosum	Presence of cristiform or crenate telia on fusiform swellings.	Actual or estimated number of fusiform swellings per tree.
Wood rot fungi (i.e., *Fomes juniperinum*)	Presence of heart rot or decayed areas in trunk or branches. Fungal fruiting bodies may or may not be present.	Presence rated as light, moderate, or heavy.
Mold and/or mildew (unidentified spp.)	Fungal mycelial growth on foliage.	Presence rated as light, moderate, or heavy.
Mistletoe (*Phoradendron juniperinum*)	Presence of viable mistletoe foliage in tree.	Actual or estimated number of growth areas per tree.

habitable niches, pathogens, seasonality, and roles of predators such as grazing animals influence the diversity and stability of pinyon-juniper woodlands, as do naturally occurring catastrophic events (i.e., fire) or deliberate manipulation or intervention by man.

The ecological dynamics of the pinyon-juniper ecosystem have been studied by Pearson (1920), Woodbury (1947), Daniel et al. (1966), and Vasek (1966) and typically have been oriented toward range and resource management. Synecological studies of pinyon-juniper have included work in latitudinal and elevational patterns (Daubenmire 1943), interactions with understory vegetation (West et al. 1975), paleoecological influences (Cottam 1959), and climatic and edaphic relationships (Beeson 1974, Hunt 1974). Several studies have treated disease and/or insect factors of pinyon pines (McCambridge and Pierce 1974, McGregor and Sandrin 1968, Hepting 1921), but little research in these particular areas has dealt with juniper.

The objectives of this study were to survey the diseases of Utah juniper (*Juniperus osteosperma* [Torrey] L.), particularly those induced by fungi, and to relate their occurrence, frequency, and severity to selected environmental factors in several pinyon-juniper habitats throughout Utah.

MATERIALS AND METHODS

Seventeen representative pinyon-juniper sites in Utah were studied from April to Octo-

TABLE 2. Location of 17 primary juniper study sites in Utah.

Site name	Site no.	Weather station
Jackson Springs	1	St. George
Tobin Bench	2	Veyo Power House
Peters Point	3	Monticello
Alkali Ridge	4	Blanding
Cyclone Flat	5	Natural Bridges Natl. Mon.
Indian Peak	6	Desert Expt. Range
Ephraim	7	Ephraim Sorensens Fld.
Manti	8	Manti
Black Mountain	9	Salina
Triangle Mountain	10	Salina
Beaver Ridge	11	Beaver
Gordon Creek	12	Hiawatha
Dutch John	13	Flaming Gorge
Taylor Flat	14	Allen's Ranch
Rabbit Gulch	15	Hannah
Henry Mountains (Stevens Narrows)	16	Capitol Reef Natl. Park
Henry Mountains (Airplane Flat)	17	Boulder

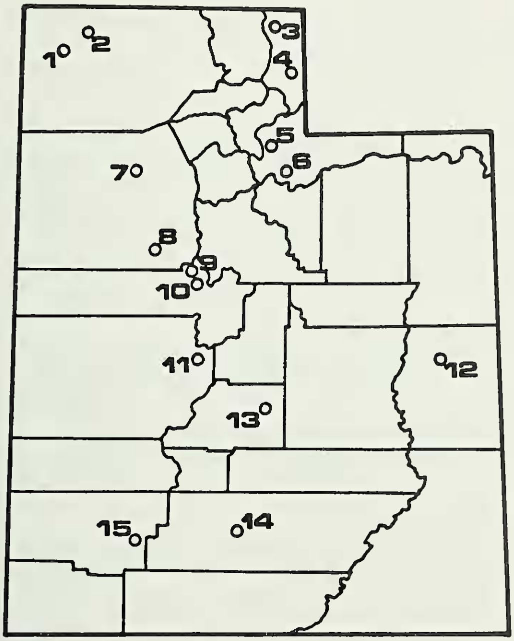

Fig. 2. Observations of four *Gymnosporangium* species in selected Utah sites.

ber 1982 (Fig. 1). Sites were selected for climax pinyon-juniper vegetation and minimal structural disturbance by people, although most sites had a long history of grazing by domestic animals and wildlife. Soils were primarily derived from marine shales, conglomerates, siltstones, and sandstones (Bunderson et al. 1985).

Transects at each site consisted of 96 Utah juniper trees randomly selected by the quarter method (Phillips 1959). Each tree was measured for height, stem diameter, and age and then assessed for signs and symptoms of disease. Diseases were classed in three causal categories: (a) rust fungi (*Gymnosporangium* spp.), (b) miscellaneous fungus diseases (e.g., tip burn, die back, stem decay), and (c) parasitic higher plants. Nonparasitic injury was also assessed. Descriptions of diseases, pathogenic agents, and assessment methods are found in Table 1. The percentage of decadence for each tree was estimated and an overall vigor score (1 = good, 2 = moderate, 3 = poor) was assigned to each tree.

Since some areas of the state were not represented in our 17 primary sites (Table 3), we added 15 additional sites (Fig. 2) in which just the incidence of *Gymnosporangium* rusts was studied. We used the standard U.S. Forest Service ratings as listed in the addendum to Table 4.

Since each site had its own pattern of infection, we calculated severity indexes to reflect both the total number of trees infected with each causal agent and the severity of that infection on each tree (Table 2).

We measured concentrations of several soil mineral nutrients (N, P, K, Ca, Mg, Na, Fe, SO_4) and other soil properties (pH, EC, sand, silt, clay) by digging five soil pits along each transect and pooling samples from the top 12 inches of soil from each pit. Soils were acid digested and analyzed for mineral content using a Technicon II Auto Analyzer and atomic absorption spectroscopy. Temperature and

TABLE 3. Observations of three *Gymnosporangium* species in selected Utah sites.

	G. inconspicuum	*G. nelsoni*	*G. kernianum*
1. Immigrant Pass	C	O	C
2. Rosette	A (*very* heavy)	A	A
3. Bear Lake	C	O	A
4. Hwy 39, 6 mi west of Woodruff	C	A	A
5. Chalk Creek	A (on both foliage and twigs)	C	C
6. Hwy 150—Yellow Pine Campground	O	O	R
7. Hastings Canyon	C	R	C
8. Lookout Pass	O	O (no live galls)	O
9. 12 mi Northeast of Eureka	O	C	C (heavy when present)
10. Silver City	R	O	N
11. Scipio Pass	C	C	A
12. Sego	A (some fasciation)	A (*very* heavy)	N
13. 2 mi south of Fremont Junction	A	O (most galls dead)	O (heavy when present)
14. Escalante Canyon	C	C	N
15. 8 mi east of Parowan	O	C	N

A = Abundant
C = Common
O = Occasional
R = Rare
N = None observed in area

precipitation records were obtained from National Oceanic and Atmospheric Administration recording stations at or near the research sites. For complete descriptions of the 17 primary site locations and weather recording stations, see Table 3. These values were divided seasonally into four quarters: December–February, March–May, June–August, September–November. Location and frequency of alternate hosts for *Gymnosporangium* rusts were also noted.

We used linear correlation coefficients to relate frequencies and severity of the diseases of Utah juniper to the soil factors, temperature, and precipitation. A nonparametric weighted least squares analysis for categorical data tested hypotheses relating interactions between the environmental data and pathogenic factors (Forthofer and Lehnen 1981). The hypotheses were checked for statistical significance and offered as a possible tool to predict the incidence of disease that would occur within a given site if the conditions of the hypotheses were met.

RESULTS AND DISCUSSION

Gymnosporangium Rusts

Frequent occurrences of *Gymnosporangium* spp. on Utah juniper have been recorded in Utah (Arthur 1934, Hodges 1962, Peterson 1967), but these occurrences have not been quantified. Figures 3 and 4 quantify the frequency of the three *Gymnosporangium* rusts we encountered most often on Utah juniper in the 17 transects.

Gymnosporangium inconspicuum Kern was present on a substantial proportion of the trees at 15 of the 17 sites. The caulicolous and/or foliicolous telia of *G. inconspicuum* are inconspicuous and difficult to locate, and probably more trees were infected than recorded. The high frequencies support observations by others that *G. inconspicuum* has a high endemic population in juniper stands throughout Utah (Peterson 1967). We examined the two sites where *G. inconspicuum* was not recorded on three separate occasions without finding any indication of this fungus. Since these sites are located in the St. George area in the warm Mohave Desert ecotype rather than in the cooler Great Basin ecotype, environmental factors may influence the occurrence of this rust in ways other than those we have measured.

We found *Gymnosporangium nelsoni* Arth. in all research sites. The galls stimulated by this rust on stems and branches of *J. osteosperma* varied from 2 to 12 cm in diameter, and both live and dead galls were counted until gall numbers exceeded 300 per tree. Excluding the St. George sites, incidence of

TABLE 4. Description of rating system for diseases of *Juniper osteosperma*.

Infection level = Number of trees infected with pathogen.

Severity

a. *G. inconspicuum* = Average rating of infections per tree
  - 0 = No infection
  - 1 = Light infection
  - 2 = Medium infection
  - 3 = Heavy infection

b. *G. nelsoni* = Average number of galls/tree

c. *G. kernianum* = Average number of witch's broom/tree

Severity Index

a. *G. inconspicuum* = $\dfrac{\text{Proportion of infected trees (expressed as a \%)}}{\text{Site rating} \div 3} \times 100$

b. *G. nelsoni* = $\dfrac{\text{Severity}}{\text{Average number galls/meter} \div \text{proportions of infected trees (\%)}}$

c. *G. kernianum* = $\dfrac{\text{Severity}}{\text{Average height of trees at site} \div \text{proportions of infected trees (\%)}}$

Mold mildew
Severity = Percentage of trees infected;
Severity index = Proportion (%) × percentage infected (severity)

Wood-rotting fungi
Severity = Sum of percentage of trees infected with trunk, branch, twig rot;
Severity index = Proportion (%) × severity

Mistletoe
Severity = Average number of broom/tree; severity index = Proportion (%) × severity

Needle blight
Severity = Average percentage of infection/infected tree; Severity index = Proportion (%) × severity

Needle cast
Severity = Average percentage of mildew on all infected trees (cumulative);
Severity index = Proportion (%) × severity

Tip dieback
Severity = Average percentage of infection/infected tree;
Severity index = Proportion (%) × severity

G. nelsoni was much more variable than that of *G. inconspicuum*.

We found *Gymnosporangium kernianum* Bethel on fewer sites than either *G. inconspicuum* or *G. nelsoni*. This species stimulates shoot fasciations (witch's brooms) on which foliicolous telia are formed. Numbers of brooms per infected tree ranged from 0 to 23 and size of brooms from 3 to 130 cm in diameter. The incidence of *G. kernianum* was considerably less than that of either *G. inconspicuum* or *G. nelsoni*. As with *G. inconspicuum*, only active infections were recorded.

Correlations between temperature and precipitation in our research sites indicate that *G. kernianum* is favored by moderate temperatures and a greater than average annual precipitation, particularly during the summer (Tables 5, 6).

We found a fourth species, *Gymnosporangium speciosum*, on only one primary site (Site 12) and one supplementary site (Sego). It forms bright orange cristiform or crenate telia on fusiform stem swellings, with loose fascications usually associated with the infected area.

Variation in host susceptibility complicates establishing cause and effect relationships with physical environmental factors for *Gymnosporangium* rusts. Differences in resistance to cedar-apple rust have been known for many years (Moore 1940) as well as differences in pathogenicity of the rust (Aldwinkle 1975). It has been suggested that the genetic variability

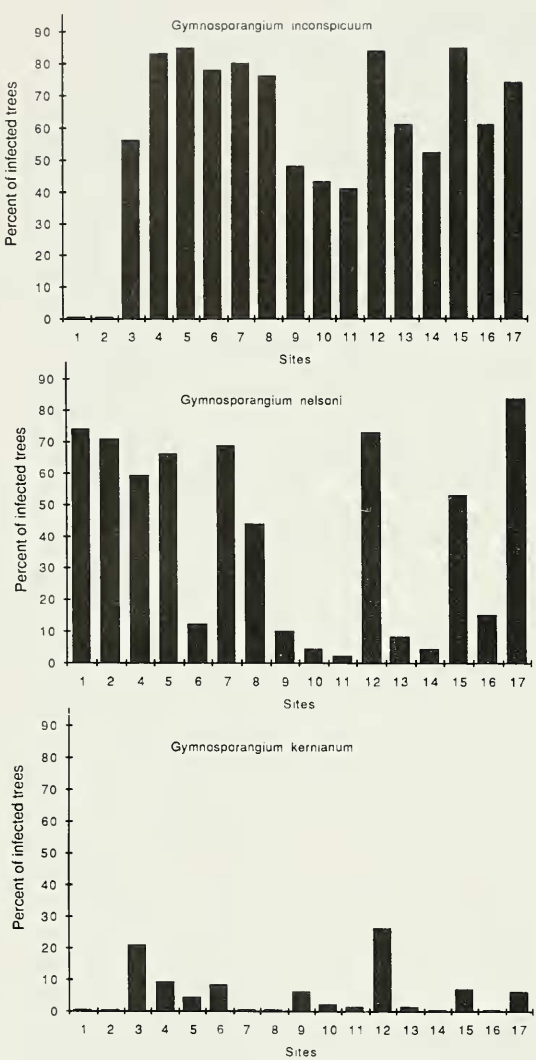

Fig. 3. The percent of infected trees (*Juniperus osteosperma*) in relation to three rusts. Top chart (*Gymnosporangium inconspicuum*), middle (*Gymnosporangium nelsoni*), bottom (*Gymnosporangium kernianum*).

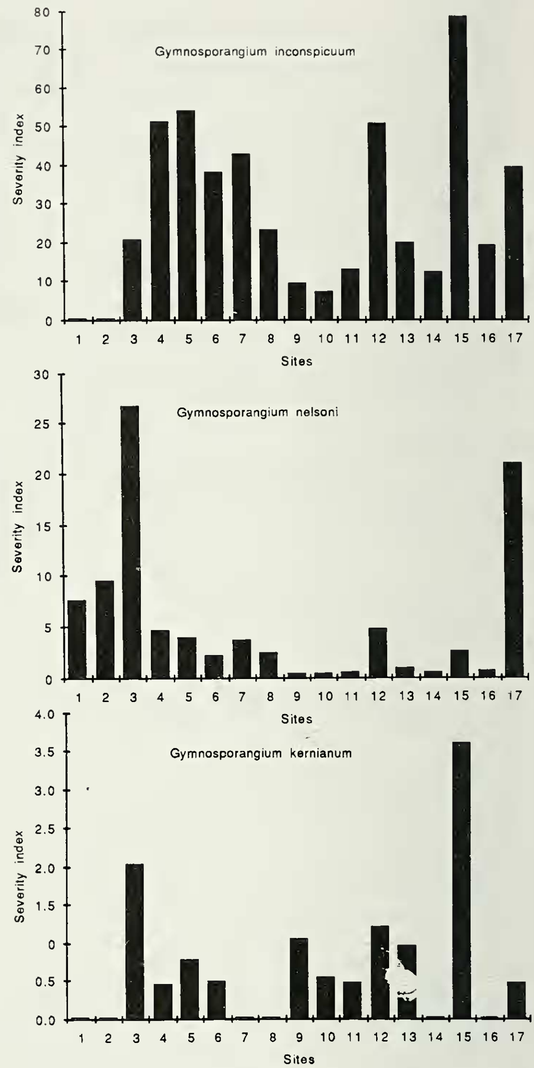

Fig. 4. The severity index of three rusts (top) *Gymnosporangium inconspicuum*, (middle) *Gymnosporangium nelsoni*, (bottom) *Gymnosporangium kernianum* on *Juniperus osteosperma* trees.

of Utah juniper may surface in the average number of stems in any given stand (Kimball Harper, personal communication). After pooling the data from the 17 sites, we found a correlation between environmental parameters such as amount of precipitation and number of juniper stems ($\alpha = 0.01$ with average annual precipitation, $\alpha = 0.05$ with summer precipitation), indicating that as the total precipitation decreases the number of stems increases. However, there are also positive correlations between increasing numbers of stems and the increased frequencies of the various rusts ($\alpha = 0.05$ for *G. nelsoni*, $\alpha = 0.10$ for *G. kernianum*). *Gymnosporangium inconspicuum* has been described as either foliicolous or caulicolous, and our data indicate that *G. inconspicuum* on the foliage correlates positively to the number of stems of *J. osteosperma* ($\alpha = 0.10$) and the caulicolous form of *G. inconspicuum* correlates negatively to the number of stems ($\alpha = 0.10$). Further studies are needed to understand these correlations.

Miscellaneous Fungus Diseases

Several types of wood-decay fungi were indicated along our transects (Figs. 6, 7) by

TABLE 5. Correlations between *J. osteosperma* diseases and insects and temperature in the different time quarters (Q).

	5-year average				Hi Q	Low Q	Annual	5-year	5-year
Pathogen	Q_1	Q_2	Q_3	Q_4	average	average	average	high	low
Needle blight	−.55*	−.45	−.40	−.55*	−.43	−.63*	−.51*	−.14	−.44
Needle cast	−.04	.12	.10	.13	.02	−.09	.10	.07	.12
Tip dieback	−.14	−.06	−.11	−.21	−.12	−.08	−.16	.20	−.35
Mold-mildew	−.46	−.49*	−.37	−.41	−.52*	−.47*	−.46	−.38	−.15
Galls-foliage	.07	−.11	.00	.14	−.09	.18	.04	−.37	.41
Galls-branch	−.27	−.32	−.24	−.20	−.33	−.19	−.26	−.64*	−.09
Witch's broom	−.43	−.55	−.41	−.45	−.56*	−.34	−.50*	−.56*	−.18
Lesions-foliage	−.30	−.34	−.44	−.33	−.38	−.22	−.33	−.26	−.23
Lesions-branch	−.65**	−.55*	−.37	−.47*	−.43	−.54*	−.51*	−.63**	−.29
Rot-twigs	−.21	−.05	−.09	−.11	−.16	−.50*	−.13	−.13	−.14
Rot-trunk	−.48*	−.38	−.25	−.39	−.37	−.39	−.39	−.06	−.30
Mistletoe	.10	.04	.13	.14	.13	.11	.13	−.29	.15
Insect borers	−.47*	−.21	−.12	−.38	−.16	−.56*	−.33	−.09	−.48*
Scale insects	−.22	−.29	−.36	−.30	−.31	−.30	−.29	−.38	−.19
Insect galls	.19	.20	.15	.12	.34	.41	.17	.35	−.09

* Significant at .05 level
** Significant at .01 level

TABLE 6. Correlations between *J. osteosperma* diseases and insects and precipitation (p) and the four different time quarters (Q).

Pathogen	P Q_1 High	P Q_2 High	P Q_3 High	P Q_4 High	P Q_1 Low	P Q_2 Low	P Q_3 Low	P Q_4 Low	Average annual precipitation
Needle blight	−.71**	−.38	.02	−.09	−.26	.10	.68**	−.00	−.46
Needle cast	−.00	−.22	−.21	.34	.39	−.19	.10	−.37	−.27
Tip dieback	−.44	−.13	−.20	−.29	−.34	.01	.04	.19	−.25
Mold-mildew	−.19	−.31	.02	.58*	−.05	−.05	.47*	−.29	−.09
Galls-foliage	.80**	.34	.31	.67**	.30	.12	−.10	−.11	.75**
Galls-branch	.40	−.15	.67**	.40	−.21	−.13	.14	.09	.53*
Witch's broom	.35	−.08	.64**	.53*	−.05	.04	.25	.05	.57*
Lesions-foliage	−.03	−.12	−.02	.32	.49*	−.04	.18	−.19	−.15
Lesions-branch	−.09	−.52*	.25	.47*	−.10	−.44	.34	.11	.06
Rot-twigs	−.42	−.51*	.05	.13	−.02	−.27	.42	−.25	−.53*
Rot-trunk	−.29	−.38	−.14	.43	.02	−.20	.18	−.14	−.21
Mistletoe	−.03	−.22	.08	.29	−.11	−.29	.03	−.31	−.07
Insect borers	−.89**	−.79*	−.03	−.22	−.63**	−.40	.46	.01	−.71**
Scale insects	−.38	−.18	.23	−.09	−.18	.19	.61**	−.10	−.22
Insect galls	−.02	.22	−.47*	−.38	−.12	−.04	−.39	.16	−.03

* Significant at .05 level
** Significant at .01 level

decayed areas and fruiting bodies. Only tentative identifications of the species were made. Fourteen sites contained trees with wood rot (2–64 trees/transect). The incidence of unidentified fungal diseases on the foliage (mold-mildew) was very similar (Figs. 7, 8) to that of the wood-rotting fungi. These mold-mildew fungi may be similar to those recorded by others (Hodges 1962, USDA Index of Plant Diseases 1960, Horst 1979), i.e., *Cercospora* spp., *Stigmina* spp., *Phoma* spp., *Dimerium* spp., etc. We observed the symptoms of leaf-tip burn, shoot-tip dieback, leaf-needle blight, and needle cast but did not establish specific causal agents for these diseases.

Distinct negative correlations existed between the amount of mold-mildew occurring in a site and temperatures at the site ($\alpha = 0.05$ with spring and summer temperatures) and definite positive correlations between the amount of mold-mildew and the amounts of summer ($\alpha = 0.01$) and fall ($\alpha = 0.05$) precipitation. This corresponds to behavior of foliage pathogens (such as phomopsis, cercospora blight, etc.) in which moderate temperatures

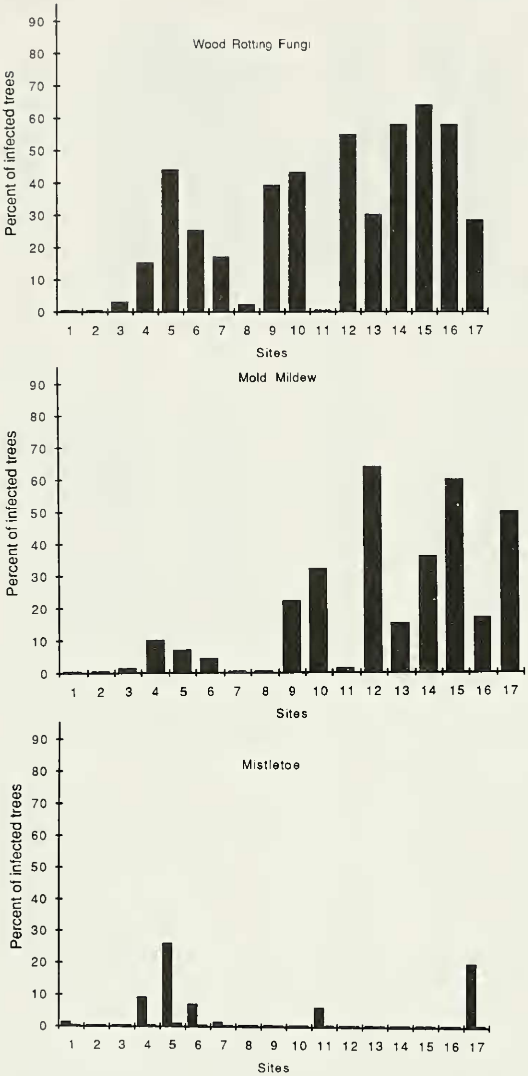

Fig. 5. The percent of trees (*Juniperus osteosperma*) infected with wood-rotting fungi (top), mold mildew (middle), and mistletoe (bottom).

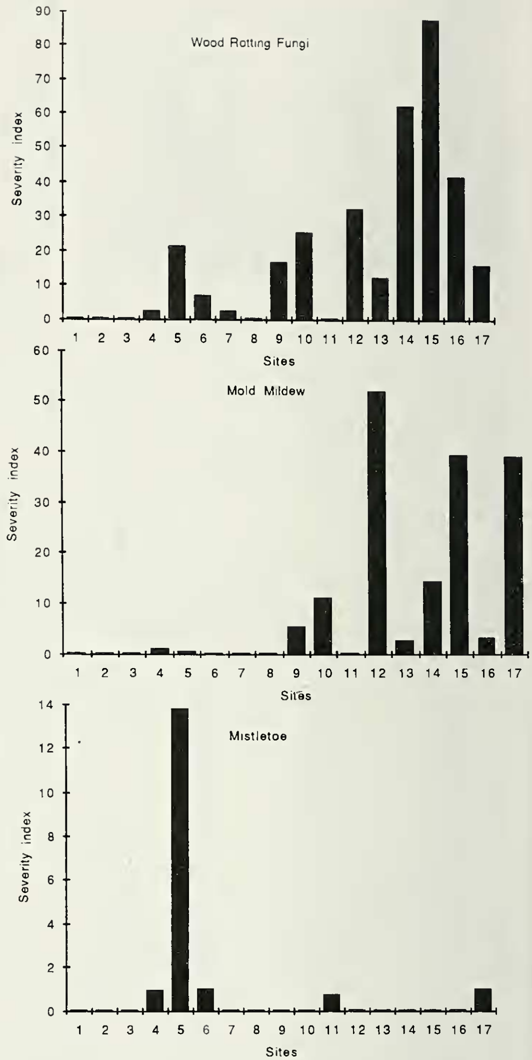

Fig. 6. The severity index of wood-rotting fungi (top), mold mildew (middle), and mistletoe (bottom) on *Juniperus osteosperma* trees.

and high amounts of relative humidity and/or free moisture favor infection. Incidence of wood-rotting fungi seems to be correlated with low winter temperatures ($\alpha = 0.05$), and no correlations exist with amounts of precipitation. There is, however, high correlation with the incidence of wood-rotting fungi in the host and variations in amounts of soil nutrients. If the nitrogen supply to the host is relatively low, the frequency of wood-rotting fungi on the host is greater ($\alpha = 0.05$).

Parasitic Higher Plants

True mistletoe (*Phoradendron juniperium*) Englm. has been reported on Utah juniper in Utah by Hawksworth and Wiens (1966) and in Arizona by Hreha (1978). We found *Phoradendron juniperium* in seven of our transects (Figs. 5, 6).

Injuries of Unknown Origin

A third disease category was designated as injuries of unknown origin. Diseases in this

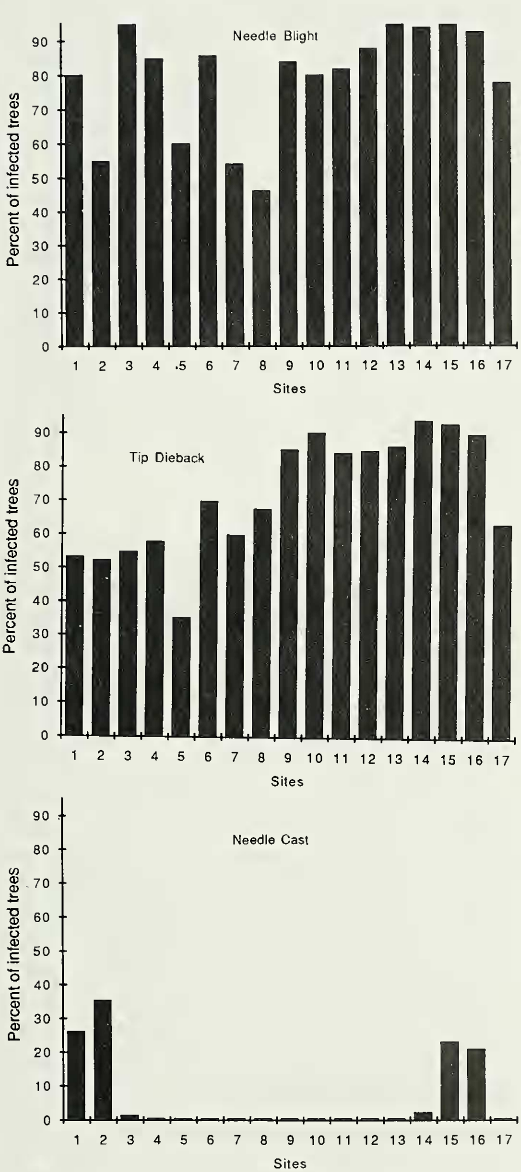

Fig. 7. The percent of infected trees (*Juniperus osteosperma*) with needle blight (top), tip dieback (middle), and needle cast (bottom).

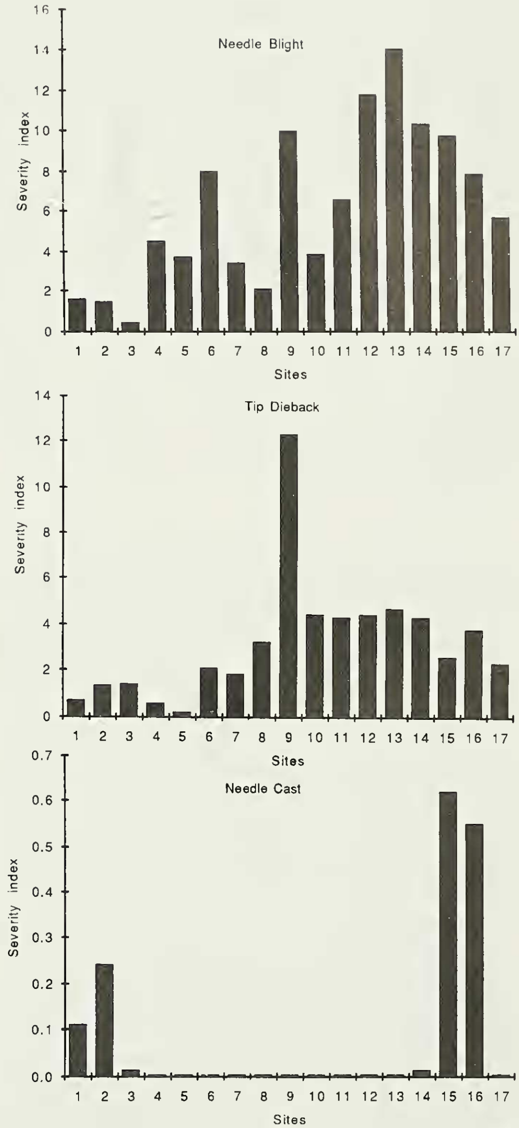

Fig. 8. The severity index of three diseases: needle blight (top), tip dieback (middle), and needle cast (bottom) on *Juniperus osteosperma* trees.

category had symptoms similar to the tip-burn, tip-dieback, needle blight, needle cast, and general chlorosis (Figs. 5, 6, 7, 8). Environmental factors such as desiccation, winter injury, high temperature, and nutrient imbalances could cause these injuries. Since some could also be induced by biotic agents, however, we classified them as being of unknown origin. Isolates from these tissues produced a variety of fungi, most of which were probably saprophytes. Although a variety of fungi were isolated from these tissues, their pathogenicity was not established. Consequently, no specific cause was assigned for these diseases.

It was possible, however, to separate injuries into three groups (Figs. 7, 8) as was done earlier by Horst (1979). Symptoms of needle blight and tip dieback occurred at every site, and needle-cast was observed on approximately one-third of the sites.

TABLE 7. Correlations between *J. osteosperma* diseases and insects versus soil variables.

Pathogens	pH	ECx10^3	%N	ppm P	ppm K	ppm Ca
Needle blight	.31	.51*	−.37	−.12	.20	−.52*
Needle cast	.21	−.12	−.10	−.24	−.01	.32
Tip dieback	.31	.26	−.08	.66**	.43	−.04
Mold-mildew	.09	.01	−.47*	−.27	.28	.08
Galls-foliage	−.32	−.34	.07	−.19	−.39	.41
Galls-branch	−.21	−.13	−.33	−.22	−.34	.27
Witch's broom	−.15	−.18	−.43	−.18	−.20	.17
Lesions-foliage	.49*	−.07	−.15	−.17	.12	.02
Lesions-branch	.15	−.08	−.70**	−.47*	−.03	−.02
Rot-twig	.26	.11	−.22	−.38	.07	−.03
Rot-trunk	.20	−.08	−.57*	−.20	.48*	−.02
Mistletoe	−.23	−.11	−.20	−.33	.11	−.19
Insect borers	.29	.24	−.62**	−.18	.49*	−.29
Scale insects	.23	.54*	−.16	−.22	−.03	−.34
Insect galls	.30	−.24	.18	.56*	.44	.31

* Significant at .05 level
** Significant at .01 level

The incidence of needle blight was the most responsive of the three diseases to variations in the environmental factors we measured. Incidence was consistently negatively correlated ($\alpha = 0.05$) with sites that had low temperature periods throughout the year, and particularly for the low winter temperatures ($\alpha = 0.01$). The correlation with precipitation was similar. Needle blight was more intense in those sites with the lowest winter precipitation ($\alpha = 0.05$). Incidence of needle blight was positively correlated with summer drought ($\alpha = 0.01$). These results suggest that environmental stress contributes significantly to this symptom, and it may be the result of desiccation or winter injury. The pinyon-juniper woodlands rely heavily on winter precipitation to replenish soil moisture since precipitation in other periods of the year is sporadic. In areas where soil reserves are marginal, moisture deficits during hot summer months may produce the symptoms we observed.

The incidence of needle blight was also correlated with two soil factors (Table 7). Sites with a higher soil salinity as measured by the electrical conductivity (EC) had higher percentages of trees with needle blight. That this may be a direct response is supported by previous work (Bunderson 1983) in which small elevations in the amount of EC in the soil were correlated with lower concentrations of total chlorophyll in the foliage of Utah juniper. The amount of total soluble carbohydrate in the foliage increased with higher EC in the soil, which may indicate a decrease in the metabolic efficiency of the plant. The correlation ($\alpha = 0.05$) of needle blight with the amount of calcium in the soil indicates that, when calcium is relatively plentiful, the percent of needle blight on the site is lower, and we hypothesize that as soil calcium content increases, the detrimental effect of salinity on Utah juniper is ameliorated.

Tip dieback, while also having a moderate negative correlation with low winter precipitation, has no correlation with temperature. Contrary to expectations, tip dieback was more common on trees with higher nitrogen levels in the foliage ($\alpha = 0.05$) and higher phosphorus ($\alpha = 0.01$) and potassium ($\alpha = 0.10$) levels in the soil. Until fungi can be associated with these symptoms and pathogenicity established, relationships to other factors remain speculative.

Gymnosporangium Rusts

The most frequent juniper pathogens we encountered on our research sites were the *Gymnosporangium* rust fungi. These rust fungi are parasitic and most are heteroecious. The alternate hosts of *G. inconspicuum* and *G. kernianum* are species of *Amelanchier*, most commonly *A. utahensis* Koehne. (*A. alnifolia* Nutt. is also a frequent alternate host for *Gymnosporangium* rusts, although usually for those species that parasitize Rocky Mountain juniper (*Juniperus scopulorum* (Sarg.) rather than *J. osteosperma*). *Gymnosporangium nelsoni* has been found on *Amelanchier* and, locally, on *Peraphyllum ramos-*

ppm Mg	ppm Na	ppm SO-S	ppm Fe	% Sand	% Silt	% Clay
−.06	−.25	.24	.17	−.21	−.24	−.20
.23	.24	.07	−.28	−.04	−.09	.26
.27	−.27	.27	.29	−.23	−.27	.11
.18	−.01	.00	−.22	.04	−.06	.07
.09	.45	−.49*	−.28	.48*	.42	.31
−.02	.37	−.24	−.04	.39	.01	.20
.16	−.09	−.45	−.09	.54*	.27	.35
.20	−.16	.24	−.04	−.24	−.21	.18
.13	−.05	−.30	−.48*	.46	.05	.13
−.04	.25	.45	.11	−.34	−.52*	−.08
.31	−.47*	−.22	−.35	.26	.13	.12
−.38	.13	−.11	−.27	.23	−.07	−.48*
.01	−.21	.18	−.03	−.03	−.35	−.20
−.30	.28	.45	.26	−.43	−.40	−.31
.56*	−.13	−.30	−.04	.22	.35	.22

sissimum Nutt. The alternate hosts of *G. speciosum* have been reported on species of *Fendlera* and *Philadelphus* (Kern 1973).

In our transects the incidence of rust on juniper was not significantly correlated with the frequency and close proximity of the alternate host. This was not unexpected considering the differing ecological habitats of *Amelanchier* and *Juniperus* species. Since basidiospores are capable of traveling considerable distances and remaining viable (Parmelee 1968), and because aeciospores may remain viable as long as one year (Miller 1932), alternate hosts need not to be in close proximity for infection of either to occur.

Temperature and moisture requirements for the release of *Gymnosporangium* basidiospores have been well documented by Pearson et al. (1980), Pady and Kramer (1971), and Pearson et al. (1977). Although little is known about the specific requirements for infection of juniper, it is obvious that these requirements were met in our research sites (Table 8). *Gymnosporangium speciosum* and *G. kernianum* were less widespread than either *G. inconspicuum* or *G. nelsoni*. Peterson (1967) noted that *G. kernianum* is absent from many stands throughout the Great Basin where both hosts occur together. Our data support this observation.

A Predictive Model

Disease occurrences are determined by complex environmental interactions and causal agents. In the present study we have used descriptive data to develop hypotheses for correlating the incidence of disease with climate, soil, and other site factors in Utah juniper habitats.

Distributions of several of the disease variables were sufficiently peaked or had such high degrees of skewness that the populations did not fit the normal distributions that are implicit in correlational or factor analyses. Even though the correlations in our study are unusually stable because of the size of our data base (96 trees in each of 17 sites), nonparametric methods of analysis were used to generate predictive models from our data.

We applied the weighted least squares analysis for categorical data (Forthofer and Lehnen 1981). Using the environmental variables that generally encourage the growth and proliferation of fungi causing mold and/or mildew symptoms, the following hypotheses were generated:

1. High amounts of fall precipitation characterize sites with high amounts of mold-mildew on the foliage.
2. Low summer temperatures characterize sites with high amounts of mold-mildew on the foliage.
3. High nitrogen nutritional status of the plant is conducive to low amounts of mold-mildew on the foliage.

Five of the 17 sites were selected, each of which contained trees infected with a mold/mildew pathogen. Each of these sites also differed from the others on the three environmental variables chosen to formulate the three hypotheses. The hypotheses can be reflected as linear weights where:

TABLE 8. Correlations between *J. osteosperma* diseases and insects and site characteristics.

pathogen	Distance	Height	Diameter	Age	Soil depth
Needle blight	−.45	−.45	−.13	.24	−.38
Needle cast	.54*	−.21	.20	.08	−.33
Tip dieback	−.23	−.39	−.13	.12	−.30
Mold/mildew	−.17	−.02	.21	.21	−.34
Galls-foliage	.43	.66**	.05	−.26	.24
Galls-branch	.16	.48	−.10	−.15	−.02
Witch's broom	.19	.47*	.22	.15	.07
Lesions-foliage	.17	−.41	.06	−.05	−.53*
Lesions-branch	−.29	.41	.28	.53*	−.02
Rot-twig	.13	−.41	−.14	.10	−.55*
Rot-trunk	−.27	.09	.61**	.69**	−.03
Mistletoe	−.41	.20	−.16	−.02	.08
Borers	−.57*	−.27	.01	.55*	−.30
Scale insects	−.25	−.63**	−.67**	−.55**	−.59**
Insect galls	.02	.12	.11	−.05	.19

* Significant at .05 level
** Significant at .01 level

1 = The hypothesis is true for this site.
−1 = The hypothesis is not true for this site.
0 = This site was not considered when making this hypothesis.

These weights were entered into the following X matrix where row 1 is equivalent to site 5, row 2 to site 6, row 3 to site 9, row 4 to site 14, and row 5 to site 15.

X Matrix:

Row 1	1	0	1	1
Row 2	1	0	1	0
Row 3	1	1	−1	0
Row 4	1	0	−1	−1
Row 5	1	−1	−1	1

Column 1 represents the presence or absence of mold/mildew at each of the selected sites. Since each site was selected because mold/mildew was present, column 1 is a constant. Column 2 represents the linear weights of hypothesis 1; column 3, hypothesis 2; and column 4, hypothesis 3. From this matrix of linear weights based on our hypotheses, we have predicted the incidence of mold-mildew at sites 5, 6, 9, 14, and 15. The predicted and observed occurrences of mold/mildew expressed as proportions of infected trees are presented below. From the small residual figures, the success of the three hypotheses at predicting the proportion of infection seems good.

Site	Observed	Predicted	Residual
5	.073	.074	−.001
6	.042	.041	.001
9	.229	.228	.001
14	.375	.377	−.002
15	.625	.624	.001

The overall chi^2 (X^2) goodness of fit for the observed versus predicted data was 0.004, and the beta weight for the matrix constant (column 1) was 0.226. The beta weights for each of the hypotheses were −0.181, −0.184, and 0.033. The very small chi^2's and the small residual values indicate an excellent fit for the hypothetical model to the observed incidence of mold-mildew. The hypotheses were tested for significance of the X^2 values:

Hypothesis 1 = 27.7
Hypothesis 2 = 126.3
Hypothesis 3 = 1.6

Significance of X^2 values:

.05 level 3.84
.01 level 6.63
.001 level 10.83

Using this procedure we can affirm that high amounts of fall precipitation and low summer temperatures do indeed characterize sites with high amounts of mold-mildew on Utah juniper foliage. The first two hypotheses of our model have reliably predicted the proportion of trees in a pinyon-juniper site that could be expected to be infected with mold-mildew. The third hypothesis was not confirmed.

As can be seen from the predictive ability of the generated hypotheses and the power to statistically confirm their validity, such a nonparametric statistical model offers a valuable tool for understanding the interactions between the many variables that exist in any ecosystem.

Vigor	Decadence	Density	Slope	Elevation	Exposure	Alternate host
.38	.22	.32	−.21	.33	−.20	−.09
−.01	.09	−.53*	−.20	−.03	.05	.25
.36	.04	.10	.05	.12	−.25	−.05
−.07	.64**	.08	.05	.52*	−.37	.34
−.56**	.16	−.31	.01	.04	−.10	.27
−.45	.16	−.16	.19	.54*	−.06	.51*
−.67**	.55*	−.19	.06	.49*	.04	.39
.02	.05	−.14	−.14	.17	.31	.39
−.40	.55	.25	.08	.60**	.17	.37
.29	.03	−.19	.00	.15	−.30	.13
−.34	.89**	.27	.02	.34	.06	.33
−.07	.10	.58*	.05	.37	.01	.44
.30	.33	.45	.18	.51*	−.12	.12
.60**	−.40	.20	−.14	.44	−.11	.21
.16	−.21	−.18	.48*	−.19	.09	−.08

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